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RADIOACTIVITY IN THE HYDROLOGIC ENVIRONMENT

PROJECT RULISON

FINAL PRE-SHOT REPORT (U)

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CONTENTS

Figures

Tables

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1.0 INTRODUCTION

Project RULISON is a Plowshare experiment to determine the commercial feasibility of nuclear stimulation of natural gas reservoirs[1]. Surface ground zero (SGZ) is located on the southwest limb of the Piceance Creek Basin in Sec. 25. T7S, R95W in Garfield County, Colorado (Figure 1). The proposed nuclear detonation, with a yield of 40 kilotons, is to take place at a buried depth of 8430 feet in rocks of the Mesaverde Group (Figure 2).

2.0 AVAILABLE INFORMATION

The Mesaverde Group, at the Rulison Site, is an approximately 2500 foot thick sequence of interbedded sandstone and shale. The Mesaverde Group overlays the Mancos Shale Formation and is overlain in ascending order by the Ohio Creek Conglomerate, about 37 feet thick, an unnamed unit of Paleocene age (possibly Fort Union or lower Wasatch), about 500 feet thick, the Wasatch Formation, about 3900 feet thick, the Green River Formation, about 1700 feet thick, and Quaternary alluvium as terrace, and streambed deposits (Figure 2).

All rocks in the Project RULISON region contain ground water. The amount and source of ground water used in the immediate explosion area is unknown. At Morrisania Mesa, about three miles northwest of SGZ, ground water is withdrawn from saturated alluvium for domestic use[2,3] surface water from Battlement Creek is used for irrigation[2,3].

The USGS interpreted the chemical character of fluids collected from tubing after each drill stem test in exploration hole R-EX as indicating that "little mobile water occurs in the zones tested"[2].

Predicted physical effects for a 40 kiloton explosion include formation of a rubble chimney 144-216 feet in diameter and 301-451 feet high, with

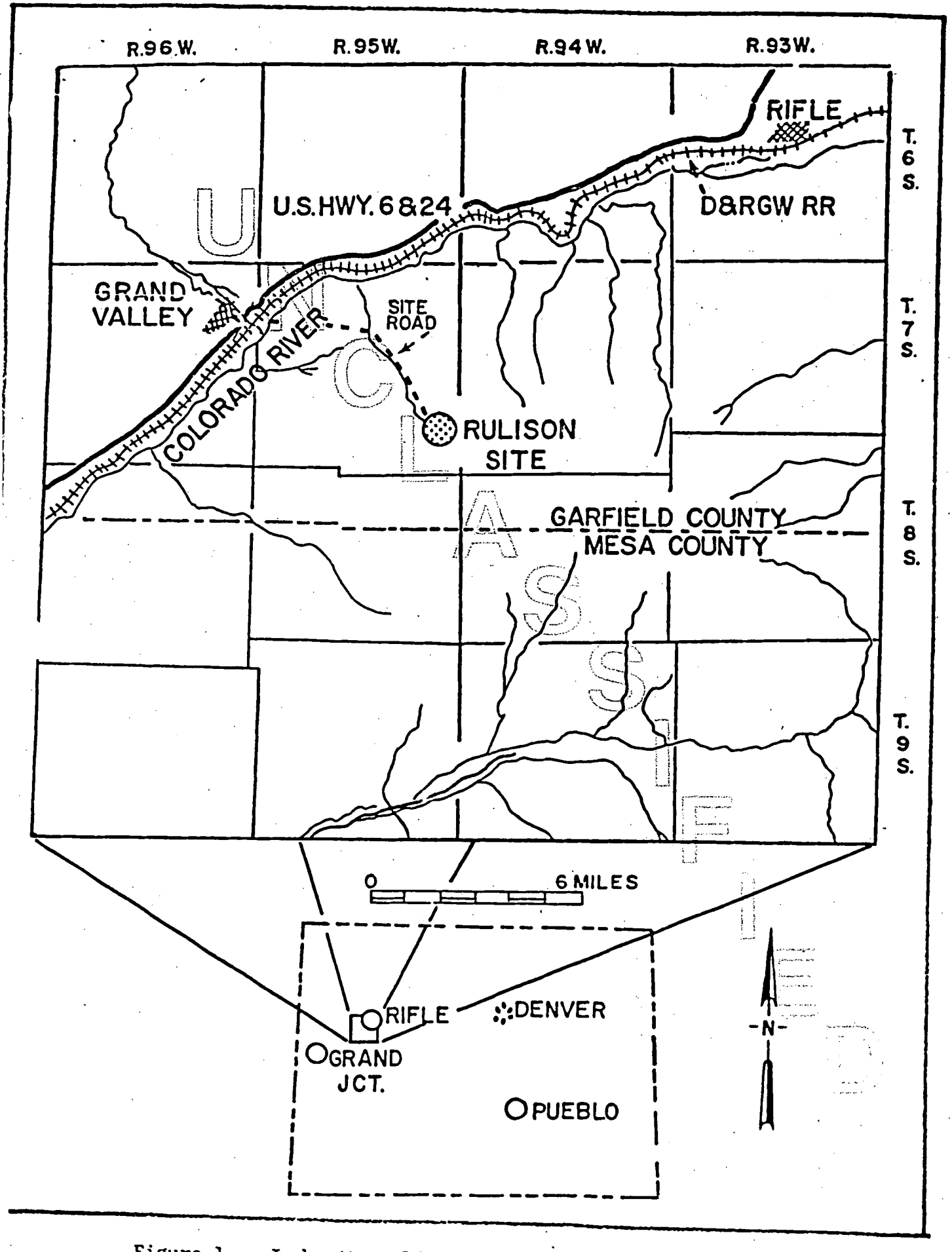

Figure 1. Index Map of Project Rulison Site (map from PL-4-5-69(1))

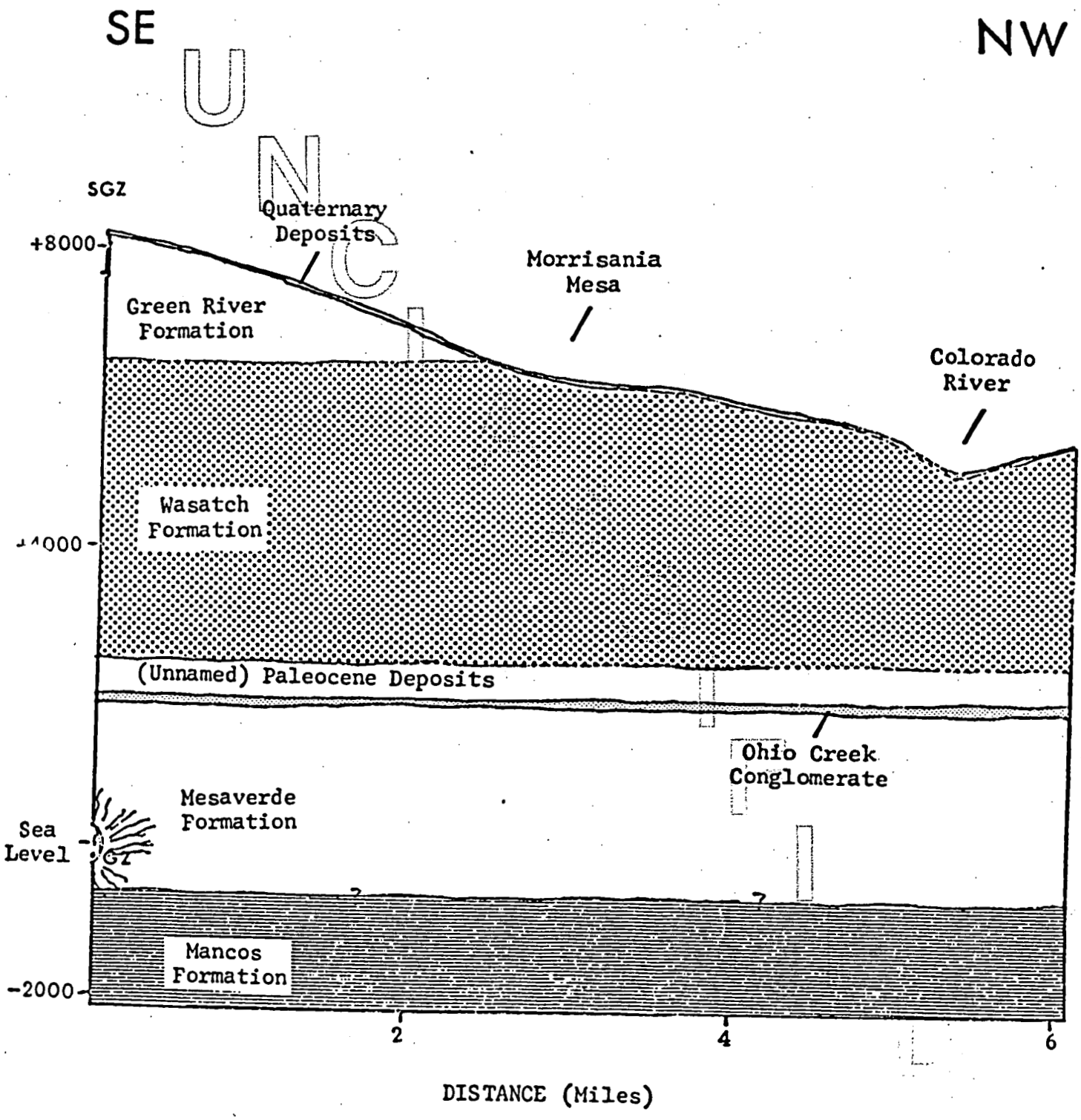

Figure 2. Diagrammatic Cross Section of RULISON Site Along Trend of Battlement Creek

fractures extending beyond the chimney limits for a total distance of up to 580 feet[4].

Estimates of quantities of radionuclides present at T_o + 180 days are given in Table I. Of the nuclides listed several will exist as gases (Kr, Xe, H, CH_4) and as volatiles (I, Cs, H_2O); others will be refractory (Sr, Y, Ru, Ba). Only those radionuclides having half-lives greater than one-half year (Kr^{85}, Sr^{90}, Ru^{106}-Rh^{106}, Cs^{137}, Pm^{147}, and H^3) are considered significant in evaluation of hazard to the hydrologic environment. Data from the Gasbuggy Event suggest tritium will have the following distribution: 70 to 90 percent will be incorporated into water, 9 to 27 percent into molecular hydrogen, 1 to 3 percent into methane, and 0.03 to 0.1 percent into ethane.

3.0 ASSUMPTIONS AND ESTIMATES

Although some hydrologic tests were performed on Ohio Creek and Mesaverde rocks encountered in exploration drill hole R-EX, virtually no information was obtained about the hydraulic properties of the rocks. No laboratory tests to measure chemical exchange properties of the rocks were performed. There is presently no way of knowing the quantity of water that may be available to mix with radionuclides. Appropriate conservative assumptions must therefore be made.

The direction of ground water flow in the alluvium is assumed to be northward, consistent with topographic slope. Rocks below the alluvium dip two degrees or less to the north[2]. Ground water flow in these rocks is assumed to be northward also.

All of the nuclides produced from this device except Kr^{85}, Xe^{133}, and H^3, may be retarded by chemical exchange.

Rock materials such as those at the RULISON Site retard the movement of radioactivity in varying degrees. The rate of movement of any particular isotope, relative to ground-water velocity, is dependent upon the nature of the rock constituents, porosity, and competition of the isotope with other dissolved constituents in the transporting fluid. Values for retardation of dissolved constituents is calculable from a laboratory measurement of the distribution coefficient, Kd, for the specific dissolved constituent and rock type through which transport will occur.

Although Kd's were not determined for the rocks at the RULISON Site, experience and analyses made on rocks of varying types from other locations permits a reasonable approximation for retardation of nuclides for this report. Values for Kd previously determined by Isotopes are given in Table II.

Source term concentrations were estimated by assuming that the explosion-related nuclides as shown in Table I are completely and uniformly mixed with a quantity of water equivalent to the volume of the cavity void space anticipated to be formed by the detonation. This assumption is conservative, leading to high values for radionuclide concentrations, because it is known that significant fractions of refractory nuclides will be incorporated in the melt. On the other hand, significant fractions of volatile or refractory nuclides having gaseous precursors (such as Sr^{90} and Cs^{137}) will be distributed in the rubble chimney. The cavity volume is calculated to be about 2×10^6 to 5×10^6 cubic feet (0.5×10^{11} to 1.5×10^{11} milliliters). In this water volume, tritium concentration would be about 60 to 200 CG*, namely $1. \times 10^4$ curies per 1.5×10^{11} milliliters to $1. \times 10^4$ curies per 0.5×10^{11} milliliters or about 6×10^{-2} microcuries (μCi) per milliliter (ml), to 2×10^{-1} μCi/ml.

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* An abbreviation for Concentration Guides. CG's are reference concentrations as given in November 8, 1968 revision of USAEC Manual, Chapter 0524, Standards for Radiation Protection, Annex A, Table II, Column 2, reduced by a factor of three to be consistent with standards applicable to Individuals and Population Groups in Uncontrolled Areas. These guides are applied as per instructions in TN NV 0500-23, dated May 12, 1969. A CG is used in the same context as an MPC had previously been applied.

Table I. Radionuclide Activity at T_o + 180 days
Resulting from Detonation of 40 Fission Kilotons.

Nuclide	Half-life	Curies
Kr^{85}	10.76 y	0.96×10^5
Sr^{89}	50.6 d	0.91×10^5
Sr^{90}	28.8 y	0.59×10^4
Y^{91}	59 d	1.01×10^5
Zr^{95}	65 d	1.82×10^5
Nb^{95}	35 d	0.32×10^5
Ru^{103}	40 d	0.41×10^5
Rh^{103}	57 min	0.41×10^5
Ru^{106}	1.0 y	1.52×10^5
Rh^{106}	30 sec	1.52×10^5
I^{131}	8.05 d	1.13
Xe^{133}	5.27 d	0.86×10^{-3}
Cs^{137}	30 y	0.75×10^4
Ba^{137}	2.6 min	0.69×10^4
Ba^{140}	12.8 d	0.34×10^5
La^{140}	40 h	0.40×10^5
Ce^{141}	32.5 d	0.52×10^5
Pr^{143}	13.7 d	0.63×10^5
Ce^{144}	285 d	1.47×10^5
Pr^{144}	17.3 min	1.47×10^5
Pm^{147}	2.6 y	0.28×10^5
H^3	12.27 y	$1. \times 10^4$

TABLE II.

Distribution Coefficients of Strontium-85 and Cesium-137 for various materials. Material suspended in 4 parts saturating solution for 72 hours. Minimum particle diameter is 4000μ.

Material	Saturating Medium	Kd (Ml/g) Sr	Kd (Ml/g) Cs
Basalt (Amchitka)	Sea Water	1.07	6.50
Carbonate (Yucca Flat, Nevada Test Site)	Prepared Water* (Well)	0.19	13.5
Salt (Tatum Salt Dome)	Salt Saturated Water	0.19	0.027
Shaley Siltstone (Gasbuggy Site, Northern New Mexico)	GB-2 Well Water	8.32	309.
Sandstone (Gasbuggy Site, Northern New Mexico)	GB-2 Well Water	1.37	102.
Granite (Shoal Site, Nevada)	Deep Formation Water	1.7	34.3
Tuff (Rainier Mesa, Nevada Test Site)	Prepared Water* (Rainier Spring)	260.	1020.
Desert Alluvium (Hot Creek Valley, Nevada)	Deep Formation Water	50-2450	70-2640

*Water prepared to have major chemical composition similar to that of referenced water source.

In the same water volume, strontium-90 concentration would be about 4×10^5 to 1×10^6 CG, namely 0.59×10^4 curies per 1.5×10^{11} to 0.5×10^{11} milliliters or 4×10^{-2} to 1×10^{-1} μCi/ml.

4.0 RADIOACTIVITY IN THE HYDROLOGIC ENVIRONMENT

The exaggerated overburial of the RULISON device is predicted to assure containment with only a low probability of release of radioactivity to the atmosphere by fissures or stemming/casing failure. It seems reasonable to assume, therefore, that essentially all of the explosion nuclides will be retained within the Mesaverde Formation.

If ground water in the Mesaverde Formation is immobile, all radioactivity will reside essentially in place until artificially removed, and will decay eventually to concentrations below one CG. For the source term concentrations given earlier, six to eight half-lives or about 75 to 100 years is required to reach tritium CG, and about 16 to 20 half-lives orabout 450 to 550 years to reach strontium-90 CG.

If the water in the Mesaverde Formation is mobile, very likely the velocity of movement will be slow enough and chemical-exchange retardation high enough to prevent transport of nuclides in greater-than-CG concentrations for any significant distances. Even if rate of ground water movement is one foot per day, explosion-produced tritiated water could move only about seven miles before it would decay below one CG. Under the same conditions of movement but with consideration of retardation effects (assuming $K_d = 10$), strontium-90 would probably move less than a mile before decay to below one CG.

In the unlikely event of venting, or other mass movement of radioactivity upwards to the land surface, tritium could be introduced into the shallow ground water in the Quaternary alluvium and/or into the surface water of Battlement Creek. Gaseous and volatile nuclides, including gaseous precursors to many refractory nuclides, could move significant distances under these conditions. However, after decay to refractory nuclides of the same mass number, such as strontium-90 from krypton-90 and bromine-90, further mass movement would be extremely retarded.

Anticipated concentrations of any near-surface explosion nuclides would be considerably less than the concentrations expected to exist under the containment conditions cited earlier.

Should tritium in water reach the land surface it would very likely not be at or above one CG If it were, and if the tritiated water remains in the ground water system, it will probably not reach Morrisania Mesa, or any other known water use point, before transport/decay time reduced it to below CG levels.

If the explosion-produced tritiated water became part of the Battlement Creek flow system, significant dilution could be expected to reduce concentrations before any long-distance transport occurred. Other explosion nuclides, in either system, would be greatly retarded and travel very short distances before decay and dilution would reduce concentrations to below CG levels.

5.0 SUMMARY AND CONCLUSIONS

In the absence of specific information on the hydraulic and chemical-exchange properties of the rocks at the RULISON Site, conservative estimates were made in order to make contamination predictions. Source term concentrations for tritium and strontium-90 were assumed to be 6×10^{-2} to 2×10^{-1} μCi/ml and 4×10^{-2} to 1×10^{-1} μCi/ml, respectively. Assumption of high but credible water movement rates and reasonable retardation effects, indicates that neither tritium or strontium-90, for example, would move more than a few miles before decay or dilution to below CG levels. In the unlikely event of mass movement of radioactivity upwards to the land surface, transport of nuclides rates might exceed those at depth, but greater-than-CG levels of activity are not expected any any known water use point.

UNCLASSIFIED

REFERENCES

(1) U. S. Atomic Energy Commission, May 1969, Project RULISON Planning Directive. PNE-G-10

(2) Voegeli, Paul T. Sr., April 4, 1969, Geology and Hydrology of the Project RULISON Exploration Hole, Garfield County, Colorado, RULISON-- USGS - 747-16. PNE-G-2

(3) CER Ceonuclear, March 26, 1969, Project RULISON Definition Plan, Sections 1, 2, 3, 4, 6, 7. PNE-G-11

(4) U. S. Atomic Energy Commission, June 1969, Effects Evaluation for Project RULISON. NVO-43. PNE-G-4